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(72) Inventors:  
• **Kauffman, Donald C.**  
**Morristown, NJ 07962-2245 (US)**  
• **Judd, Thomas D.**  
**Morristown, NJ 07962-2245 (US)**

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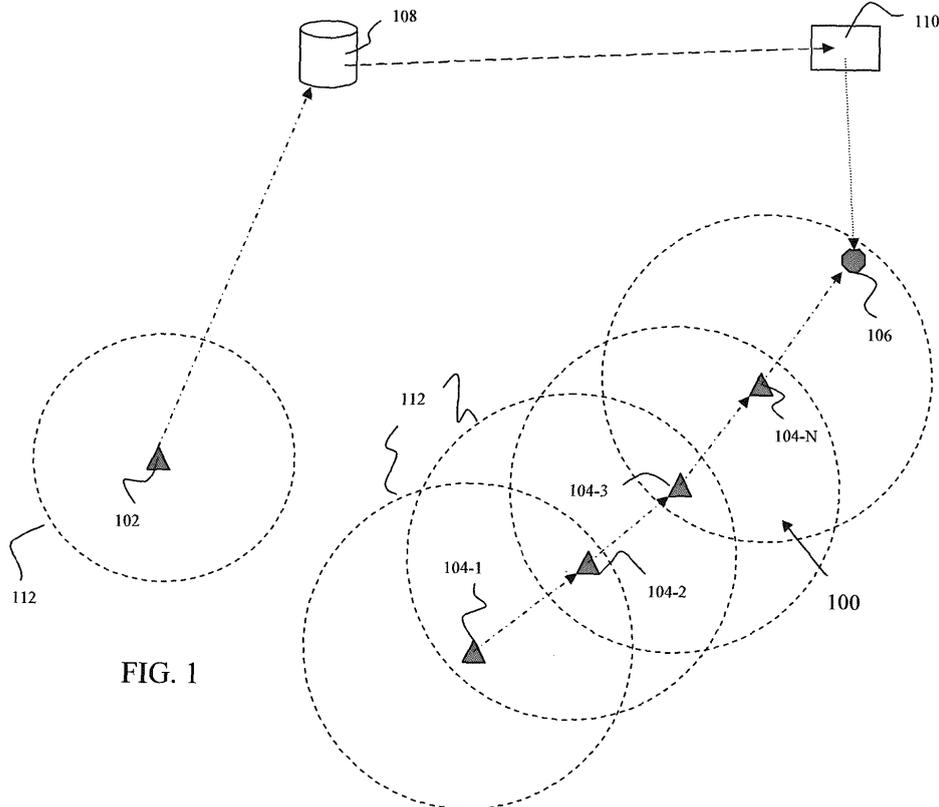
(74) Representative: **Buckley, Guy Julian**  
**Patent Outsourcing Limited**  
**1 King Street**  
**Bakewell**  
**Derbyshire DE45 1DZ (GB)**

(71) Applicant: **Honeywell International Inc.**  
**Morristown, NJ 07962 (US)**

(54) **Use of alternate communication network to complement an ad-hoc communication network of aircraft**

(57) A method of communicating aircraft messages is provided. The method comprises forming an at-hoc communication network of mobile nodes. Communicating messages between the mobile nodes via the at-hoc

communication network using mobile node-to-mobile node communication signals and supplementing communication gaps in the ad-hoc communication network with alternative communication signals.



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## Description

### Background

[0001] The use of mobile nodes to form ad-hoc communication networks provides an efficient and effective method of exchanging messages between mobile nodes as well as between a mobile node and stationary or fixed stations. For example, an ad-hoc communication network of mobile nodes can be used to relay messages to a fixed station from an originating mobile node that is beyond the communication range of the fixed station. In this example, the message is passed from one mobile node to the next mobile node that is in the direction of the fixed station until a mobile node is within the communication range of the destination station. The message is then passed onto the destination station. The use of ad-hoc communication networks eliminates the need to install and maintain significant numbers of fixed stations so that at least one will be within radio range of every mobile node traveling through a coverage area. While, the use of a mobile node-to-mobile node relay system (ad-hoc communication network) will serve many mobile nodes, it is impossible to guarantee that every mobile node will be equipped to set up the ad-hoc communication network or that there will be a sufficient number of mobile nodes positioned within the radio range of each mobile node so that a route can be found for the message from the originating mobile node seamlessly to the destination station.

[0002] For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an efficient and cost effective way to fill in gaps in routing options in an ad-hoc network.

### Summary of Invention

[0003] The above-mentioned problems of current systems are addressed by embodiments of the present invention and will be understood by reading and studying the following specification. The following summary is made by way of example and not by way of limitation. It is merely provided to aid the reader in understanding some of the aspects of the invention.

[0004] In one embodiment, a method of communicating mobile node messages is provided. The method comprises forming an at-hoc communication network of mobile nodes. Communicating messages between the mobile nodes via the at-hoc communication network using mobile node-to-mobile node communication signals and supplementing communication gaps in the ad-hoc communication network with alternative communication signals.

## Brief Description of the Drawings

[0005] The present invention can be more easily understood and further advantages and uses thereof more readily apparent, when considered in view of the detailed description and the following figures in which:

Figure 1 is an illustration of a communication system of one embodiment of the present invention;

Figure 2, is a block diagram of a mobile node communication system of one embodiment of the present invention; and

Figure 3 is a message communication flow diagram of one embodiment of the present invention.

[0006] In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the present invention. Reference characters denote like elements throughout Figures and text.

## Detailed Description

[0007] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the claims and equivalents thereof.

[0008] Embodiments of the present invention provide a method of filling gaps in service coverage for an ad-hoc communication network of mobile node network. Although, the below mobile node-to-mobile node communication networks are described in relation to aircrafts, the invention can apply to any type of ad-hoc mobile node-to-mobile node network. For example, such mobile-mobile node networks could include, but are not limited to, ground traversing military vehicles and even soldier radio networks. Hence the present invention is not limited to ad-hoc air-to-air communication networks. In one embodiment, communication satellites are used to fill in service coverage for an ad-hoc mobile node-to-mobile node communication network. In aeronautical communication embodiments, the individual strengths between the two communication systems are complementary to each other. Ad-hoc air-to-air communication networks work well where the aircraft are relatively densely spaced. Some communication satellite services, however, have a limitation that they cannot service a large

number of aircraft in a small geographical region due to bandwidth limitations and/or are more expensive to use, which makes them less desirable for aeronautical communications. However, the strengths and limitations of both the air-to-air network and the communication satellite network align in such a way to make a very cost effective aeronautical communication network with world wide coverage in both dense and sparse airspace when compared to prior art solutions.

**[0009]** Referring to Figure 1 a communication system 100 of one embodiment is illustrated. The communication system 100 includes aircraft 102, aircraft 104 (1-N), satellite 108, satellite ground station 110, and ground station 106. In this example, both aircraft 102 and aircraft 104-1 have messages to be communicated to ground station 106. The communication radio ranges 112 for each aircraft is also illustrated in Figure 1. Communication signals (mobile node-to-mobile node signals) used for aircraft-to-aircraft communications (mobile node-to-mobile node communications) are typically line of sight communication signals such as but not limited to very high frequency (VHF) signals. In regards to aircraft 104-1, the associated message is passed along through aircraft (mobile node) 104-2, 104-3 and 104-N using the air to air communication signals until it is passed on to the destination node 106 (the ground station 106). As illustrated, the path through aircrafts 104 (2-N) to ground station 106 is possible because each aircraft 104 (2-N) is within the radio range of the aircrafts 104 (2-N) sending the message. Although, Figure 1 only illustrates the aircraft 104 (1-N) that pass the message to the ground station, it will be understood that other aircraft within the radio range could have been included in an ad-hoc network but only those aircraft that were included in the routing path are illustrated.

**[0010]** In contrast to the passing of the message to the ground station 106 via the air-to-air network of aircraft 104 (1-N), the message generated by aircraft 102 needs help in reaching the ground station 106 because of a gap in the coverage. Since, aircraft 102 is not within the air-to-air communication range (or mobile node-to-mobile node communication range) of another aircraft in the direction of the ground station 106 or the ground station itself, an alternative means of communicating the message is used. In this example, once aircraft 102 discovers it cannot pass the message on to the destination node or another aircraft of an air-to-air communication network, it uses a satellite communication means to pass the message on to the destination node. Referring to Figure 1, the message is sent from the mobile node 102 to a satellite 108. The satellite 108 then sends the message to a satellite ground station 110 which in turn communicates the message to the destination node 106. In another embodiment, the alternative communication means is a high frequency (HF) communication network including a HF transceiver 108 and an HF ground station 110. Still in other embodiments other air/ground (alternative) communication methods are used such as VHF

consumer (non-aeronautical specific) and any similar communication network that serves aircraft. Moreover, it is contemplated that the destination node may not be a ground station but another aircraft or other type of mobile node.

**[0011]** Figure 2 illustrates a vehicle communication system 200 of an aircraft of one embodiment of the present invention. The vehicle communication system 200 includes a communication management function (CMF) 210 that controls the communication of the vehicle communication system 200. In this embodiment, the vehicle communication system 200 includes two transceivers, a communication transceiver 214 and a satellite (or HF or VHF or other system) transceiver 250 in communication with the CMF 210. The communication transceiver 214 sends and receives signals via antenna 218 and the satellite transceiver 250 sends and receives messages via antenna 252. The communication transceiver 214 is used to send and receive the air-to-air signals to other aircraft. The satellite transceiver 250 is used to send and receive the alternative signals that are used to communicate with a satellite HF, VHF or other system. The vehicle communication system 200 also includes surveillance equipment 201. The surveillance equipment 201 is used to send and receive surveillance information such as vehicle position and vehicle identification. Aircraft use the surveillance information for collision avoidance reasons. As illustrated, the surveillance equipment 201 is in communication with the CMF 210. Moreover, the surveillance equipment 201 sends and receives the surveillance information via the surveillance transceiver 212 and antenna 216. In one embodiment, the surveillance equipment is used to provide position and identification information of other aircraft to the CMF 210, which uses the position and identification information to discover the topology of the ad-hoc communication network and communication paths through topology. In another embodiment, message exchange with overhead data, on the air-to-air communication network, relating to position and identification is exchanged between the aircraft to determine the topology and communication paths.

**[0012]** Figure 3 illustrates a message flow diagram 300 of one embodiment. This method starts by generating a message to be sent by an originating aircraft 302 (or originating node). The originating node then determines if it is within communication range of the destination node (304). The communication range is the communication range for the mobile node-to-mobile node communication signals. Such signals could include but are not limited to very high frequency (VHF) signals. If the destination node is within the communication range (304), the message is sent to the destination node (320). If however, the destination node 320 is not within the communication range (304), it is determined if a complete path to the destination node is available via mobile node-to-mobile node network (306). In embodiments, it is not only determined that another mobile node is within communication range but also whether the other mobile node is in the

general direction of the destination node or a route through a plurality of mobile nodes can be established in the general direction of the destination node. If a complete route to the destination is not available (306), the level of urgency of the message is determined (314).

**[0013]** In this embodiment, messages that are determined to not be urgent are held on to until a later time. However, if a message is determined to be urgent it is sent right away by the alternative communication means (or system). In particular, in this embodiment, if the message is determined as being urgent (314), the message is sent via the alternative communication means (316). The message is then communicated to the destination via the alternative system (318). If the message is determined not to be urgent (314), it then determines if a maximum wait time for the message was accrued (309). If a maximum wait time for the message has accrued (309), the message is sent via the alternate communication means (316). If a maximum wait time for the message has not accrued (312), a select amount of time is allowed to pass without attempting to resend the message (312). After the select amount of wait time, the process continues at (304) where it is again determined if the mobile node is within range of the destination node. Although, this embodiment only categorizes messages as urgent and not urgent it is contemplated that various level of urgency can be assigned to a message with each level warranting a different response (for example, providing different waiting periods before transmission based on the level of urgency). The period of time can be configured for all messages or for each message independently. In other embodiments, messages are held on to for a period time for other reasons such as quality of service reasons, cost of sending the signal, message type, message priority, required reliability, required security, acceptable transit delay and phase of the flight (or mobile node mission). Regarding the cost example, the messages may be held on to for a period of time due to costs associated with using the alternative communication means. Hence, a message in one embodiment is only sent to an alternative network if the available alternative network has an acceptable cost. The mobile node in the ad-hoc network may wait until another ad-hoc route in general direction of the destination becomes available or until a low cost alternative network becomes available. Moreover, in one embodiment, the message urgency is a function of the cost, phase of flight, and/or quality of service. Hence, the present invention is not limited to systems basing the transmission on acceptable delivery time, cost of delivery, quality of service or phase of flight but other factors can be used to determine how a message urgency should be handled during periods implementing the alternative communication system.

**[0014]** Referring back to Figure 3, when a mobile node-to-mobile node route to the destination is determined (306), the message is sent via the mobile node-to-mobile node network to the destination (310). The mobile node that receives the message then starts the process over

at (304) where it determines if it is within the communication range of the destination node. This process further continues as indicated in Figure 3, until the message is received at the destination node.

**[0015]** The methods and techniques used by the CMF as described above to communication messages in an ad-hoc communication network and supplement routing paths with alternative communication signals are implemented in digital electronic circuitry, or with a programmable processor (for example, a special-purpose processor or a general-purpose processor such as a computer) firmware, software, or in combinations of them. Apparatus embodying these techniques may include appropriate input and output devices, a programmable processor, and a storage medium tangibly embodying program instructions for execution by the programmable processor. A process embodying these techniques may be performed by a programmable processor executing a program of instructions to perform desired functions by operating on input data and generating appropriate output. The techniques may advantageously be implemented in one or more programs that are executable on a programmable system including at least one programmable processor coupled to receive data and instructions from, and to transmit data and instructions to, a data storage system, at least one input device, and at least one output device. Generally, a processor will receive instructions and data from a read-only memory and/or a random access memory. Storage devices suitable for tangibly embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and DVD disks. Any of the foregoing may be supplemented by, or incorporated in, specially-designed application-specific integrated circuits (ASICs).

**[0016]** Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

## 50 Claims

1. A method of communicating aircraft messages (300), the method comprising:

forming an ad-hoc communication network of aircraft (308);  
communicating messages between the aircraft via the ad-hoc communication network using rel-

- atively short range communication signals (310); and supplementing communication gaps in the ad-hoc communication network with relatively long range communication signals (316).
2. The method of claim 1, wherein the relatively long range communication signals include at least one of satellite, high frequency (HF) and very high frequency (VHF) signals.
3. The method of claim 1, further comprising:
- determining actions to be taken relating to the relatively long range communication signals based on provided factors (314).
4. The method of claim 3, wherein the determined actions include at least one of transmitting the relatively long range communication signals, not transmitting the relatively long range communication signals and waiting for a period of time before transmitting the relatively long range communication signals.
5. The method of claim 3, wherein the provided factors include at least one of urgency of the message, the quality of service, the cost of service and the class of the message.
6. The method of claim 3, wherein the determined actions comprises:
- based on the determined actions, waiting for a period of time before transmitting the relatively long range communication signals (312); once the period of time has passed (312), determining if another aircraft is within the relatively short range communication signals communication range (306); and if another aircraft is within the relatively short range communication signals, transmitting the message to another aircraft via the relatively short range communication signals (310).
7. The method of claim 1, wherein forming an ad-hoc network of aircraft further comprises:
- discovering the topology of aircraft within the relatively short range communication signals.
8. The method of claim 7, wherein communicating messages between the aircraft via the at-hoc communication network using relatively short range communication signals further comprises:
- determining a route through the topology in the general direction of a destination node, wherein the destination node is one of an aircraft and a
- ground station; and passing a message through the discovered topology based on the determined route (310).
9. A program product comprising program instructions embodied on a processor-readable medium for execution by a programmable processor (210), wherein the program instructions are operable to cause the programmable processor to:
- form an ad-hoc communication network (112) between mobile nodes (104), wherein the communication network is made up of mobile nodes that are within mobile node-to-mobile node communication range of each other; determine a path for a message through the ad-hoc communication network towards a destination node (106); and when a gap is encountered in the path to the destination node through the ad-hoc communication network of mobile nodes, use an alternative communication system (108, 110) to supplement the ad-hoc communication network.
10. The program product of claim 9, wherein the program instructions are further operable to cause the programmable processor to:
- delay the use of the alternative communication system for a period of time based on predetermined factors.

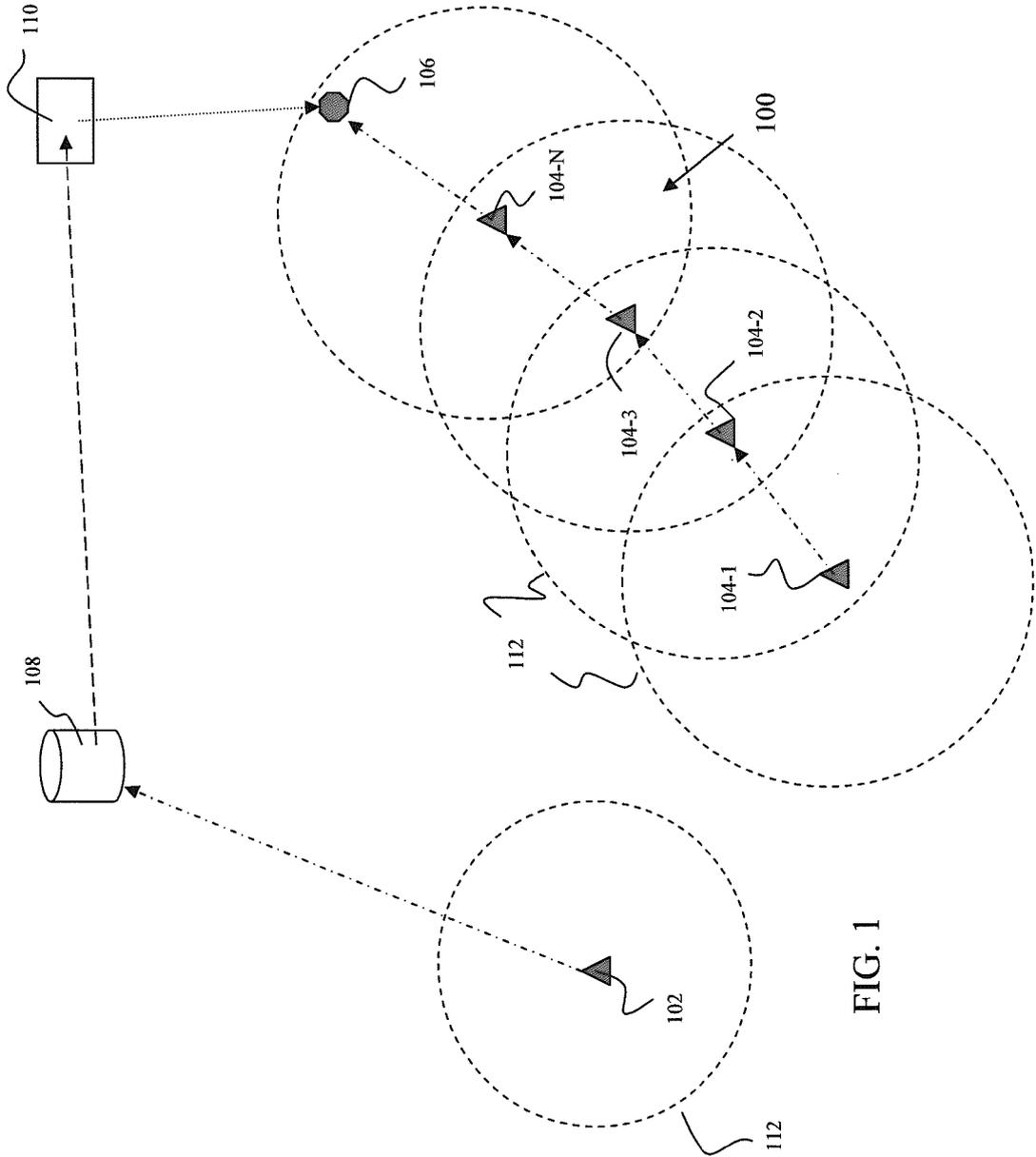


FIG. 1

200

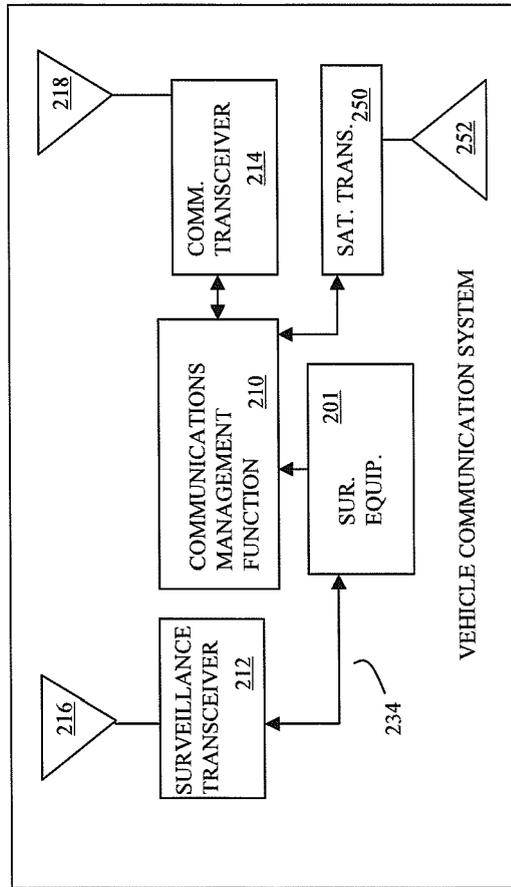


FIG. 2

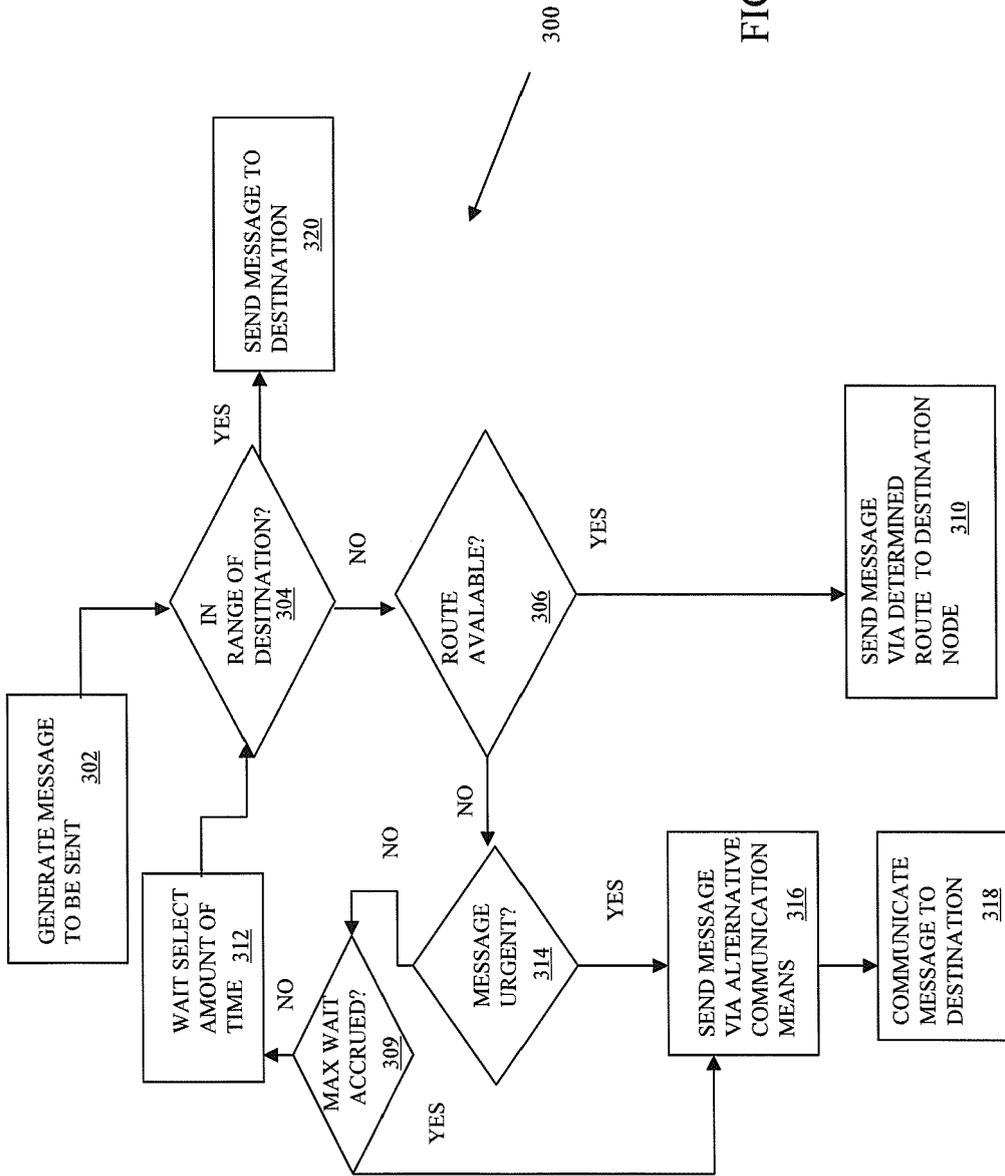


FIG. 3



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Application Number  
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| CATEGORY OF CITED DOCUMENTS   |  | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>.....<br>& : member of the same patent family, corresponding document |  |
| X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |  |   |  |

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**ANNEX TO THE EUROPEAN SEARCH REPORT  
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